SDSS DR4: Progress on the hot white dwarf luminosity function

2009 J. Phys.: Conf. Ser. 172 012002

(http://iopscience.iop.org/1742-6596/172/1/012002)

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2012**	2. REPORT TYPE	3. DATES COVERED **00-00-2012 to 00-00-2012**
4. TITLE AND SUBTITLE **SDSS DR4: progress on the hot white dwarf luminosity function**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **U.S. Naval Observatory,PO Box 1149,Flagstaff,AZ,86002**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
Journal of Physics: Conference Series 172 (2009) 012002

14. ABSTRACT
A large collection of white dwarf (WD) spectra from Sloan Digital Sky Survey (SDSS) data release 4 (DR4) WD catalog data allowed us to obtain a luminosity function (LF)for the hottest WDs. The LF was calculated basing on spectra of the WDs from a special class of SDSS objects called hot standards (HS), for which the WD sample completeness can be estimated. WD distances were determined from the observed and absolute SDSS g filter magnitudes derived from WD stellar atmosphere model fits to the SDSS spectra. The result LF covers -0.5 up to 7 absolute bolometric magnitude range. It shows a slight disagreement at the cold end comparing to the literature LFs but it can be due to some problems with HS WD sample completeness estimations. It is clearly visible that the LF has unexpected plateau between 1.5 and 4 absolute bolometric magnitudes. There is nothing similar visible in a LF built only for non-DA WDs. The plateau might be real but we are concern that its existence can be connected to the problems with spectra calibration of the blue objects in SDSS DR4 data and lack of good stellar atmosphere models for the hottest DA white dwarfs.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

SDSS DR4: progress on the hot white dwarf luminosity function

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Abstract. A large collection of white dwarf (WD) spectra from Sloan Digital Sky Survey (SDSS) data release 4 (DR4) WD catalog data allowed us to obtain a luminosity function (LF) for the hottest WDs. The LF was calculated basing on spectra of the WDs from a special class of SDSS objects called hot standards (HS), for which the WD sample completeness can be estimated. WD distances were determined from the observed and absolute SDSS g filter magnitudes derived from WD stellar atmosphere model fits to the SDSS spectra. The result LF covers -0.5 up to 7 absolute bolometric magnitude range. It shows a slight disagreement at the cold end comparing to the literature LFs but it can be due to some problems with HS WD sample completeness estimations. It is clearly visible that the LF has unexpected plateau between 1.5 and 4 absolute bolometric magnitudes. There is nothing similar visible in a LF built only for non-DA WDs. The plateau might be real but we are concern that its existence can be connected to the problems with spectra calibration of the blue objects in SDSS DR4 data and lack of good stellar atmosphere models for the hottest DA white dwarfs.

A sample of WDs used to calculate hot WD LF was selected from DR4 WD catalog (Eisenstein et al. 2006). The catalog contains spectroscopically identified WDs from SDSS (York et al. 2000) DR4 data (Adelman-McCarthy et al. 2006), which covers 4783 square degrees of the sky with spectroscopic observations. However not all WDs from the catalog were used to build LF but only those marked as a special SDSS class of objects called HS (Krzesinski et al. 2004), which SDSS uses to calibrate the observations. Shortly, the HSs are a subclass of SDSS objects which fulfil the following criteria: their observed g filter magnitude is greater than 14 mag and dereddened g magnitude is less than 19 mag (see Schlegel et al. 1998). Their dereddened color differences $(u-g)_0$ and $(g-r)_0$ falls between -1.5 and 0 magnitudes. Objects fulfilling these requirements are allocated fibers for spectroscopy. In addition to above HS criteria, a candidate for HS has to pass some isolation and quality requirements to receive a fiber for spectroscopic observations. These requirements are very restrictive and largely decrease HS completeness. Never-less, HSs are the most complete of all stars observed in SDSS survey because of their priorities to be observed over all other star categories and its completeness can be estimated.

The SDSS HS color–color constrains restricting the sample impose a WD selection effect by cutting out more DA than DB class of WDs from the sample. In order to avoid that effect we choose to restrict our HS WD sample in the temperature. Therefore, for the analysis only WDs with $T_{\rm eff}$ greater than 23500 K and $\log g > 7.0$ were used.

To calculate our WD LF a general inverse maximum volume ($1/V_{\rm max}$) formula introduced by Schmidt 1968 was used. In the formula $V_{\rm max}$ describes a maximum volume in which a star can contribute to the LF:

$$V_{\rm max} = \tfrac{4\pi}{3}\beta c_b c_g c_{\rm HS}(r^3_{\rm max} - r^3_{\rm min})e^{-\frac{|z|}{250}}$$

where, β is the ratio of the SDSS DR4 spectral observation coverage of the sky (equals 4783, Adelman-McCarthy et al. 2006) to the total sky surface in square degrees. Since SDSS HS fiber allocation procedure strongly depends on the object Galactic latitude b and object brightness in SDSS g filter (Eisenstein et al. 2006, section 5.6) our WD sample completeness coefficient will not be a constant value. Therefore two coefficients c_b and c_g defined as linear functions of the object latitude b (c_b) and its brightness (c_g) were introduced to take care of the incompleteness due to the fiber allocation. An additional restriction comes from HS image quality. Eisenstein et al. 2006 estimates that only 77% of photometricaly targeted HS objects pass the stringent HS photometric quality flags and the third completeness coefficient $c_{\rm HS} = 0.77$ in the equation above reflects that. Finally, the $e^{-\frac{|z|}{250}}$ factor in the formula takes into account exponentially decreasing WD density with their distance z (in parsecs) from the Galactic plane. The Galactic scale height was assumed to equal 250 pc (the same as in Harris et al. 2006).

The distances to WDs were determined from observed and absolute SDSS g filter magnitudes derived from WD stellar atmosphere model fits to the SDSS spectra. However, one has to keep in mind that the DR4 WD catalog model fits show systematic errors which affect DAs with effective temperatures greater than 30 000 K (Eisenstein et al. 2006). The trend is that these model fits to SDSS spectra tend to be higher in temperature than earlier literature fits and that converts into brighter object in bolometric magnitudes ($M_{\rm bol}$). Therefore we derived a parabolic temperature correction function for the DR4 WD catalog $T_{\rm eff}$ and apply it to the whole HS DA sample. Also, since DR4 WD catalog $T_{\rm eff}$ and $\log g$ fits were calculated with LTE models, we used Napiwotzki et al. 1999 NLTE corrections to the $\log g$ and $T_{\rm eff}$ of all DAs with $T_{\rm eff} >$ 40 000 K. Taking both, the temperature and NLTE corrections into account, we calculated the LF shown in figure 1.

In the figure, bolometric magnitude bins are centered on half magnitudes and bin widths are equal 1 magnitude. For comparison we plotted WD LF by Harris et al. (2006) based on SDSS Data Release 3 (Abazajian et al. (2005) in the same figure. As one can see, the cold end of our LF is slightly above the hot end of Harris et al. LF and the displacement is greater than the error bars. The largest influence on the LF position in such diagrams is due to the WD sample completeness estimation. If that were the case, then our completeness, which basically follows the recipe given by Eisenstein et al. (2006), would be underestimated. To investigate the problem we had undertaken our own HS WD sample completeness analysis, independent on Eisenstein et al. (2006). At this moment however, we are not able to draw any certain conclusions about the completeness estimations of the HS sample.

Farther, hotter part of our LF in figure 1 goes gradually down, then became horizontal between 1.5 and 4 magnitudes which is rather an unexpected behavior. Since the LF is mostly populated by DA WDs, the flat part of the LF (or a plateau) is likely intrinsic to DAs only. To make sure that this is the case we made separate plots (not shown here) of DA and non–DA LFs, which confirmed that the plateau exists only in DA LF and not in non–DA one. By separating DA and non–DA LFs we could also demonstrate that there is a sudden drop in the space density of non-DA WDs near $M_{\rm bol} = 2$ magnitudes (which corresponds to 80 000 − 90 000 K) where the hottest part of DA LF begins. The meaning of that is such that we actually see the evolutionary

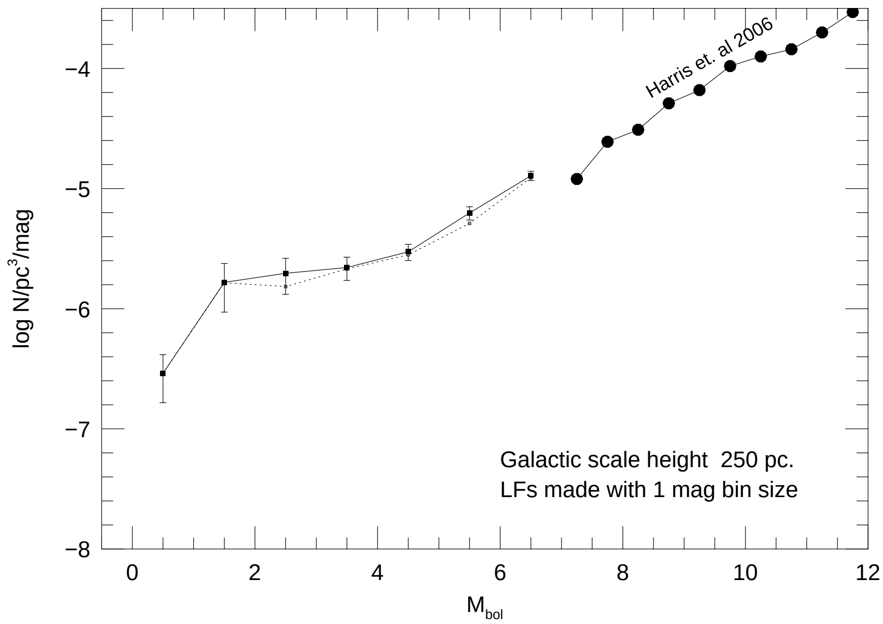

Figure 1. Hot WD LF plot for the HS sample and a bin width of 1 mag centered on a half magnitudes. The galactic scale height: 250 parsecs. Note that Harris et al. (2006) LF bin width is 0.5 magnitude.

transformation of non-DA WDs into DA ones. During the evolution temperatures of the WDs are gradually decreasing. As a consequence, approximately at 90 000 K, the effectiveness of the convective mixing in their atmospheres decreases allowing for heavier elements to settle down. That way a pure hydrogen WD atmosphere is created and a non–DA WD becomes a DA one. We start to see first DA WDs in the DA LF while at the same time the space density of non-DAs drops rapidly in the non–DA LF.

At the cold end of the non–DA LF we do not see any unexpected variations but it is worth to notice that there is no gap or any significant drop of non–DB LF within DB gap temperature region. This is due to recently found hot DB WDs (Eisenstein et al. 2006) which filled up the gap.

In a summary, the small discrepancies between our and literature LFs can be easily corrected by changes in the HS sample completeness estimation. From the other hand our LF was calculated based on distances determined from the atmosphere model fits to the SDSS spectra. That seems to be more accurate approach then any statistical proper motion method used to built the LFs in the literature. Therefore further analysis of that problem is required. A new light might bring our own (independent from Eisenstein et al. 2006) HS sample completeness estimation from SDSS targeting code but it is still under investigation.

For the moment we failed to explain the reason for the DA LF plateau presence with any physical cause but we incline to say, that the temperature and NLTE corrections we applied should have removed most of the problems with DA WD temperature and $\log g$ determinations. In that case the plateau we see in the LF is real. However, one has also keep in mind that there are other difficulties connected to the temperature determination of the hottest DAs from the atmosphere model fits. For example, metals are not included in the NLTE DA atmosphere models and their influence on the temperature determination from the models might be of order of NLTE corrections (Barstow et al. 1998). Therefore, farther investigation of the hottest part of the DA LF is required.

Acknowledgments
Funding for the SDSS and SDSS-II has been provided by the Alfred P. Sloan Foundation, the Participating Institutions, the National Science Foundation, the U.S. Department of Energy, the National Aeronautics and Space Administration, the Japanese Monbukagakusho, the Max Planck Society, and the Higher Education Funding Council for England. The SDSS Web Site is http://www.sdss.org/. The SDSS is managed by the Astrophysical Research Consortium for the Participating Institutions. The Participating Institutions are the American Museum of Natural History, Astrophysical Institute Potsdam, University of Basel, University of Cambridge, Case Western Reserve University, University of Chicago, Drexel University, Fermilab, the Institute for Advanced Study, the Japan Participation Group, Johns Hopkins University, the Joint Institute for Nuclear Astrophysics, the Kavli Institute for Particle Astrophysics and Cosmology, the Korean Scientist Group, the Chinese Academy of Sciences (LAMOST), Los Alamos National Laboratory, the Max-Planck-Institute for Astronomy (MPIA), the Max-Planck-Institute for Astrophysics (MPA), New Mexico State University, Ohio State University, University of Pittsburgh, University of Portsmouth, Princeton University, the United States Naval Observatory, and the University of Washington.

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